Wintertime Water Mass Transformation in the Labrador Sea

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LONG-TERM GOALS

To understand better the dynamics of open-ocean convection and ultimately improve its parameterization in large-scale numerical models. To meet this goal we need to understand the basin-scale setting as well as the details of the overturning.

OBJECTIVES

On the large-scale, the main objective is to determine the circulation in which the convection is embedded and distinguish the roles of the different water masses. On the small scale, the aim is to characterize the "macroscopic" mixed-layer structure as well as the “microscopic” variability within the layers, and put this structure into a consistent dynamical framework.

APPROACH

In February–March 1997 a hydrographic cruise was undertaken in the Labrador Sea during the heart of the convective season. This was part of the Deep-Convection Accelerated Research Initiative (ARI), and it was the first time that comprehensive measurements have been made during the period of active convection in this region. A total of 127 stations were occupied, each with measurement of temperature, salinity, dissolved oxygen and horizontal velocity (from the lowered ADCP). The survey covered a large region of the Labrador basin, including both the western and eastern boundaries (Figure 1a). Several small-scale “to-yo” CTD surveys were also carried out, including a 24-hour survey of a newly convected patch of water. The ship also served as a platform for an extensive air–sea flux program, atmospheric circulation study, and float/ drifter program.

WORK COMPLETED

The final calibration and processing of the CTD data set is now complete, and a data report has been put together (this will be sent to all the participants of the ARI). The lowered ADCP data set has also been processed; this represents the first direct velocity survey of the Labrador Sea. The vessel mounted ADCP data are somewhat problematic, though we fully expect to turn out a complete data set. At this point the analysis of both the large-scale circulation and small-scale mixed-layer structure have been initiated. Vertical and lateral property maps have been constructed, and detailed mixed-layer profiles have been plotted.

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SCIENTIFIC RESULTS

Large-Scale

One of the big surprises on the cruise was the fact that we observed convection along the western boundary as well as the interior of the basin. This is contrary to the conventional wisdom whereby deep convection occurs in the center of a cyclonic circulation where the isopycnals dome upward, allowing more weakly stratified water to be in contact with the surface. Our hydrographic data set has revealed two classes of convective products in the Labrador Sea: Overturning within the cyclonic circulation of the interior basin (the "gyre" product), and overturning within the rim current system (called the "Irminger" product, since the upper part of the western boundary current carries Irminger Sea water). These two products are distinct in T-S space (Figure 1): The Irminger mixed-layers are distinctly warmer, saltier, and lighter. Questions remaining to be answered include: What factors govern convection at the boundary? and Why is the interior convection limited to such a small lateral region?

Small-Scale

A characterization of the "macroscopic" properties of the observed mixed-layers has revealed intriguing differences between the two types of convective products. For example, in the interior the deepest mixed-layers are the densest, while along the boundary this is not the case. Rather, there is a limited range of T and S that results in the deepest overturning within the Irminger region (note the "ridge" of large values which cuts across density contours in Figure 2). Such features need to be understood in order to parameterize the convection accurately. Two further unexpected features of the mixed-layer structure observed in the Labrador Sea were the presence of multiple layers (two or three mixed-layers "stacked up" upon one another) and small 100–200 m "steps" within the mixed-layers themselves. We are presently investigating and nature and cause of these phenomena.

IMPACT

On the large scale, the impact of convection occurring along the western boundary is potentially huge. Exactly how and how fast newly convected water exits the Labrador Sea has been a topic of much research, and it remains unclear how efficiently the water within the interior gyre can "escape." On the other hand, convection along the boundary will occur directly into the boundary current system, hence the new water should get flushed quickly from the region and have a greater impact on the North Atlantic. On the small scale, our measurements will help to determine the dynamical framework governing the mixed-layer development and re-stratification — a crucial step toward attaining the goal of accurately parameterizing the effects of deep-sea convection.

RELATED PROJECTS

This effort is part of the Deep Convection ARI. Related projects include drifter studies, air–sea flux and atmospheric circulation programs, as well as analyses of moored data.

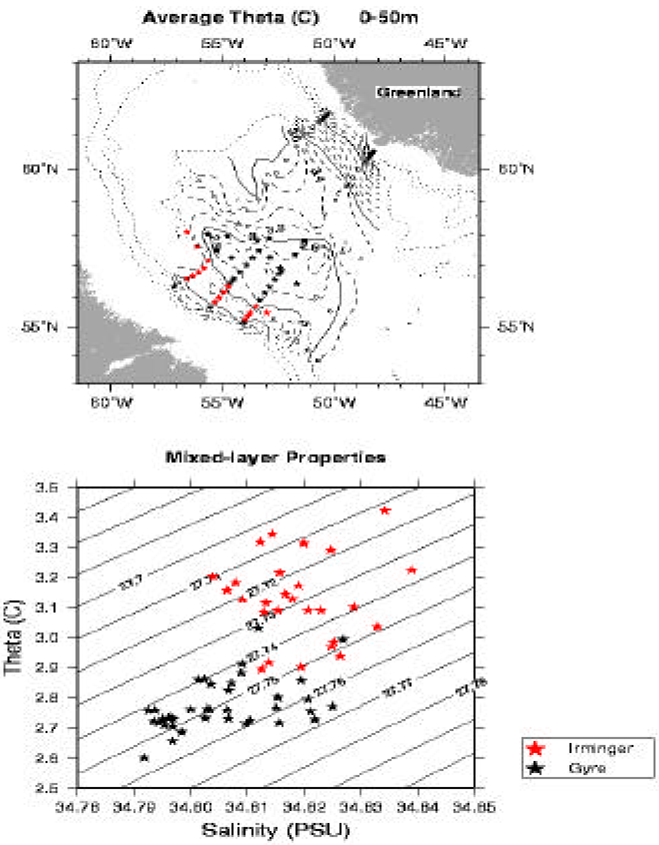

Figure 1: (a) Station positions superposed on a lateral map of near-surface potential temperature. The "gyre" and "Irminger" stations are donted by black and red stars, respectively. (b) Theta-S of the gyre and Irminger mixed-layers.

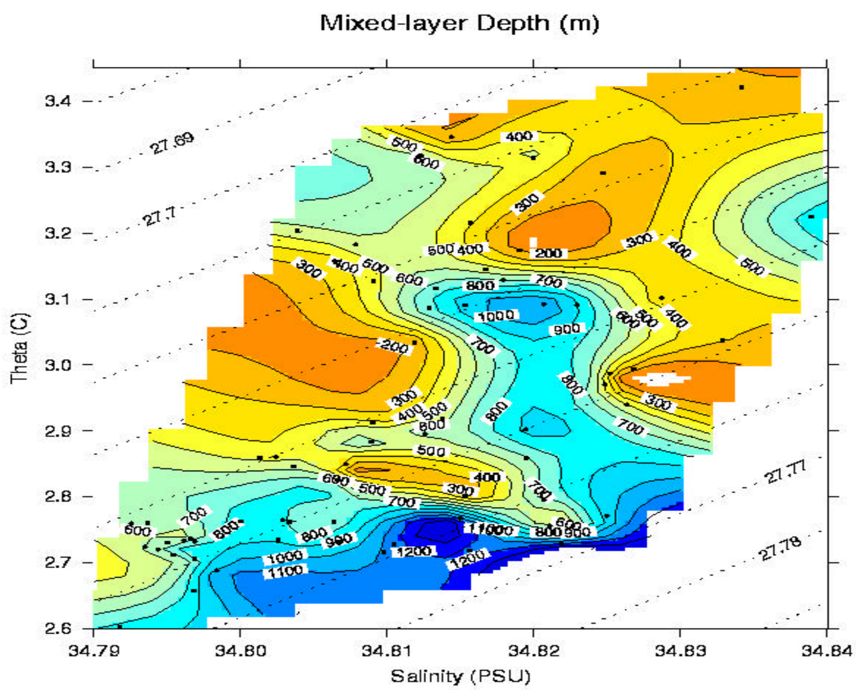

Figure 2: Mixed-layer depth, contoured as a function of Theta and S, for the gyre and Irminger regions (see Figure 1a for station locations).